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ENVRIplus DELIVERABLE

D4.1 Report on crosscutting issues, associated existing monitoring capacities and selected open case studies resulting from the Interdisciplinary workshop

WORK PACKAGE 4– Joint operations across the Research Infrastructure domains

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ABSTRACT

The workshop aims to build bridges across networks of observatories and to determine how emerging environmental research questions can benefit from these new interactions. The workshop identify key interdisciplinary challenges across subdomains that we will adopt, promote and implement within the ENVRIplus. Special attention was given on combining different networks of observatories, focusing on a few current scientific issues for societal benefit.

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TERMINOLOGY

A complete project glossary is provided online here: https://envriplus.manageprojects.com/s/text-documents/LFCMXHHCwS5hh

PROJECT SUMMARY

ENVRIplus is a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks together with technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe. It is driven by three overarching goals: 1) promoting cross-fertilization between infrastructures, 2) implementing innovative concepts and devices across RIs, and 3) facilitating research and innovation in the field of environment for an increasing number of users outside the RIs.

ENVRIplus aligns its activities to a core strategic plan where sharing multi-disciplinary expertise will be most effective. The project aims to improve Earth observation monitoring systems and strategies, including actions to improve harmonization and innovation, and generate common solutions to many shared information technology and data related challenges. It also seeks to harmonize policies for access and provide strategies for knowledge transfer amongst RIs. ENVRIplus develops guidelines to enhance transdisciplinary use of data and data-products supported by applied use-cases involving RIs from different domains. The project coordinates actions to improve communication and cooperation, addressing Environmental RIs at all levels, from management to end-users, implementing RI-staff exchange programs, generating material for RI personnel, and proposing common strategic developments and actions for enhancing services to users and evaluating the socio-economic impacts.

ENVRIplus is expected to facilitate structuration and improve quality of services offered both within single RIs and at the pan-RI level. It promotes efficient and multi-disciplinary research offering new opportunities to users, new tools to RI managers and new communication strategies for environmental RI communities. The resulting solutions, services and other project outcomes are made available to all environmental RI initiatives, thus contributing to the development of a coherent European RI ecosystem.

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INTRODCUCTION

The Science Across Observatory Networks international workshop was held in Zandvoort, Netherlands on May 9th, as part the ENVRI Plus Week. The workshop was coordinated by a committee including Abad Chabbi, INRA, France; Ari Asmi, U. Helsinki, Finland and Jean-Daniel Paris, CEA, France) and a Scientific Committee (included; Abad Chabbi, INRA, France; Hank Loescher, NEON, USA; Gelsomina Pappalardo, CNR, Italy; Jean-Daniel Paris, CEA, France; Jean-François Rolin, IFREMER, France; Karine Selegri, CNRS, France; Michael Cunliffe, MBA/NOC, UK and Thomas Dirnboeck, Umweltbundesamt, Austria.

The goal of the workshop was to build bridges and assess synergies across observatory networks -- and how emerging environmental research questions stand to benefit from such interactions. Key interdisciplinary challenges were identified across scientific subdomains, as well as strategic opportunities across Research Infrastructures. Special attention was given to combining different observatory networks to advance frontier sciences, focusing on the pre-selected scientific themes identified by ENVRI+ communities members in the form of the following 4 case studies:

1. Nitrogen from the field to the coastal ocean
2. Phytoplankton blooms from costal to open ocean
3. Arctic observation, with special focus on CH_4
4. Simulating and monitoring O_3 and CO_2 deposition/coupling/interaction

More than 70 participants were in attendance when top keynote speakers were asked to provide a comprehensive and in-depth analysis of each of the case studies that included what may be new directions for future research and infrastructures. Each case study presentation led to important follow-up discussions regarding i) where research infrastructures have yet to be created to combine subdomains (gap analyses) and ii) where further cross-disciplinary collaboration, interoperability and infrastructure improvements may be required for existing infrastructures to be successful.

1. Nitrogen, from agricultural fields to the coastal ocean: the concept of nitrogen budgets and corollary research infrastructures contributions

Over the recent years, nitrogen budgets have been developed in such a way as to become a practical policy-making tool. Originally a compilation of specific yet unconnected indicators, national N budgets are now comprised of a complete set of N flows through a nation's "metabolism". Comprehensive operational data collection and compilation has not been performed systematically yet. Growing national obligations to inventory air pollutants and greenhouse gas emissions already now provide the largest share of information needed, thus full implementation will require rather little extra effort.

In theory, N budgets are founded on the conservation of matter. However, more than 99% of N stocks may be safely ignored, as it is unreactive in the form of molecular N2 (the main constituent of the atmosphere). The "Activation" of N is the central, energy-intensive step of the process, so that only the reactive N (Nr) needs to be considered in the budgets of stocks and flows. Such Nr budgets have proven valuable in prioritizing N flows and better understanding temporal trends and spatial distribution among ecosystem types.

While the concept and guidance are largely in place, the few national budgets currently available are scientific exercises. Support from environmental agencies and administration will be required to collect data needed for a better understanding of the anthropogenic impact on the N cycle. This basic knowledge will allow to design abatement action plans aiming for alleviating environmental damage (human health, biodiversity, climate change...) generated by an excess Nr in the environment.

Infrastructures are in place in the EU to routinely monitor Nr compounds in the atmosphere (NOx, PM) as well as in groundwater (nitrate) as part of EU environmental legislation. Tall tower stations have been have been linked to allow inverse modelling of greenhouse gas emissions (as of N2O) in scientists' activities (TTORCH, InGOS) which can be extended by satellite information on NOx and N2O from platforms like ENVISAT. Biosphere-pedosphere interaction on Nr compounds in soils and groundwater are being investigated in natural ecosystems (LTER) but are much more relevant in agricultural systems that are exposed to high levels of fertilizer N. Many agricultural research institutes over Europe sport collecting this information, but little systematic interaction can be observed across national borders. All these existing activities are sectoral, but require an overarching approach. Nitrogen budgets as describing all the linking elements between pools or sectors can serve as the link urgently needed.

2. Phytoplankton blooms from coastal to open ocean

2.1 Oceanic Emissions, Marine Aerosols and Clouds

Atmospheric aerosols play a large role in air quality and human-induced climate change. After decades of research, aerosol–cloud interactions (ACI) remain the largest source of uncertainty in current estimates of global radiative forcing. This is mainly due to the fact that aerosols, clouds and ecosystem elements are intricately linked in the Earth System, via multiple interrelated forcing and feedbacks. Narrowing the uncertainties in ACI would therefore require considering all elements together, from both a mechanistic and observational standpoint. Because effects on climate are estimated from the difference between model simulations,present-day observations and preindustrial aerosol and precursor emissions, an accurate representation of number concentrations of cloud condensation nuclei (CCN) and ice nucleating particles (INP) associated with both natural background and man-made aerosols separately is critical in developing a better assessment of anthropogenic aerosol effects. As marine aerosols contribute substantially to the preindustrial, natural background which provides the baseline – on top of which anthropogenic forcing should be quantified – and because the ocean covers over 70% of the Earth's surface, the representation of marine aerosols in climate models strongly influences the predicted direct and indirect impacts of anthropogenic aerosols on climate.

Current Earth System Science models exhibit a large diversity in their representation of marine aerosol sources and sinks, as well as the processes by which these aerosols impact cloud water and ice formation. This diversity is due, in part, to the lack of measurements needed to constrain the models and the absence of a centralized network, where all available data may be accessed. Measurements of marine aerosols are challenging because of their vast spatiotemporal variability, low concentration and to the inherent difficulty in reproducing the physical scales in which they occur. However, even the available data is hard to use because of differences in the conditions is which they are collected and the methodology and instrumentation employed by different investigators. Today, key questions remain unanswered regarding the sources and sinks of marine aerosols and their impacts on clouds, limiting our ability to quantitatively predict how the climate will respond to continued and increasing greenhouse-gas and fine-particle emissions in the future.

We propose that ENVRI+ develop the integrative framework to compile and make accessible all available satellite-borne, ambient and laboratory data of marine aerosol chemical composition, CCN and INPs, meteorological, ocean physicochemical and biological state, as well as the trace gas concentrations affecting particle production and the oxidizing potential of the marine atmosphere. This is not easy; the compilation of such comprehensive datasets in a format suitable for model/data comparison would require a coordinated and multidisciplinary response and the involvement and expertise of a broad range of scientific communities. However, once the data is categorized and made accessible through a user-friendly network, the scientific community stands to save vast amounts of time and energy by avoiding unnecessary duplications. The existence of such datasets would also allow researchers to concentrate on data analyses, capturing potentially important radiative and climate feedbacks and developing subsequent discoveries.

2.2 Observations for Earth System modelling

The use of models to represent our understanding of the climate system involves coupling radiation and water cycle parameters (including cloud formation and the cryosphere), with atmospheric and oceanic dynamics. The overarching goal is to develop a climate baseline to better assess the impact of perturbations – anthropogenic, solar, astronomical or volcanic – on climate and explain non-linear behaviors in various feedback mechanisms (which, in turn, could enhance or limit said perturbations).

In the past, climate models were limited in their ability to represent feedbacks because various aspects of the system – such as atmospheric composition or vegetation – were represented as fixed static entities. However, the Earth System (ES) models that have emerged over the past decade include the representation of dynamic climate feedback in relations to the carbon cycle, atmospheric aerosols and chemistry. Thanks to ES modelling, we can now study climate-driven changes in oceanic CO2 solubility, the biological carbon pump, land productivity distribution, soil respiration and their ultimate role in climate change.

More recently, ES modelling has focused on vegetation and soils emissions (volatile organic compounds, methane, and nitrogen oxides) and couplings between atmospheric composition and radiation-driven components, such as vegetation and coral growth, evapotranspiration and river run-off, monsoon systems and permafrost thawing. State-of-the-art ES models typically include representations of the carbon cycle, ozone chemistry, wetlands and permafrost, sulfate, carbonaceous, mineral dusts and sea-salt aerosols. The most sophisticated models also include ocean biogeochemistry, stratospheric ozone chemistry and fire modelling, as well as nitrate and secondary organic aerosols. Researchers have yet to develop satisfying representations of the nitrogen cycle and ocean calcium carbonates, however.

It often takes up to 5 years to improve such models, seeing asextensive observation is required to provide insights into the process, develop numerical parameterizations and ultimately test and validate subsequent results against in-situ observations. Comparative model-data evaluations may include statistics on the frequency, strength and trends of perturbations, *a priori* and *a posteri* parameter distributions, uncertainty budget comparisons, etc... This ensures that the model aptly reflects the climate baseline and perturbations — or informs gaps in theory, observations or model(s). Spatial and temporal scales mismatches are often a challenge in such comparisons, something the research community has not been able to fully resolve. Observations typically cover hundreds of kilometers and long time-series to fully support model validation; in contrast, process understanding is often based on very fine scales.

Modelers are often pragmatic, if not opportunistic, when seeking observation datasets to support their model development and predictions. Table 1 provides a non-exhaustive list of data sources frequently used by atmospheric composition modelers. Nevertheless, initiatives the likes of the *Observations for Model Intercomparison Projects* and *Aerosol Comparisons between Observations and Models* project strive to make observations easier to use by providing modelers with datasets in gridded form, as time series and in model-friendly formats. Because many of the relevant processes occur in interface with various ES components, ground-based and *in-situ* observations are often most valuable to modelers, insofar as they also inform on processes invisible to space-borne remote sensors. For that reason, a strong case should be made to better position ENVRI+ networks in the global climate modelling landscape.

Climate variables	Examples of data source
Surface concentrations (total,e.g. PM and speciated)	Air quality monitoring networks (CREATE, EMEP, IMPROVE, NARSTO, STN), GAW-WDCA sites, field campaigns
Aerosol optical depth	Ground-based sun photometer networks (AERONET), satellite retrievals (MODIS, MISR, POLDER/PARASOL, VIIRS, AVHRR), reanalyses (MACC, NCEP), field campaigns
Aerosol size distribution, fine-mode fraction, Angstrom exponent	EUSAAR/GUAN supersites, ground-based sun photometer networks (AERONET), satellite retrievals (MODIS, MISR, POLDER/PARASOL, VIIRS), field campaigns
Total column ozone	Surface spectrophotometer network (GMD), satellite retrievals (SCIAMACHY, GOME, OMI)
Greenhouse gases	Databases (AGAGE, ESRL), satellite retrievals (GOSAT, IASI, MOPITT, TROPOMI)
Vertical profiles of aerosols and ozone	Lidar networks (EARLINET, MPLNET), satellite retrievals (GOME, OMI), active remote sensing (CALIPSO), aircraft campaigns (HiPPO)

3. Arctic observation, with special focus on CH_4

The Arctic has been shown to have increased in temperature by 0.6 o Celsius each decade for the past 30 years. This change is approximately double the global average and is projected to increase at even faster rates in the future (IPCC 2013) as part of a phenomenon referred to as the Arctic amplification. This will have unprecedented effects on both the oceanic and continental systems of the region and mitigation has become a large scientific and societal imperative — particularly for Arctic natives who rely on subsistence harvests (fish, caribou, seal, walrus, water fowl, etc.) and whose shoreline and hunting and fishing habitat are rapidly disappearing.

In the Arctic terrestrial environment, permafrost dynamics are at the heart of such changes. The top 30 or so centimeters of permafrost naturally thaw each year during the summer. However, due to increased temperatures, the thawing of the permafrost reaches deeper soil depths, directly affecting a number of ecological processes, including

i. changes in the temporal dynamics and depth of the thaw of the active layer, resulting in 'old' carbon to respire and efflux more into the atmosphere ;

ii. subsequent changes in surface hydrology;

iii. a large portion of 'old' carbon being subject to anaerobic metabolism pathways, which increase CH4 efflux;

iv. additional nutrient availability causing shifts in plant community composition, peak productivity and woody encroachment;

v. increased storage of ground heat flux and darker albedo, which in turn initiate convective boundary layers, lightning and lightning-induced tundra fires (further converting carbon into the atmosphere);

vi. an increase in the length of summer and induced seasonal 'edge effects' on ecosystem processes;

vii. lake CH4 production under ice and the concentration of CH4 'bubbles' as well as

viii. strong evidence of CH4 consumption by soils.

The continental scale spatial dynamics of CH4 at high latitudes are also poorly understood. Model and measured results show 'tipping point' temperatures – in which mass permafrost thaws and CH4 production occurs – differ in the North American continent and in Asia. Moreover, mean annual temperatures in Northern Siberia are increasing, while they are cooling in Southern Siberiabut the mechanism at play is not known.

Methane has a higher global warning potential than CO2, circa 28 times stronger over a 100-year period and with an average ten-year lifetime in the atmosphere. The processes responsible for the development of CH4 from natural sources have yet to be explained, though they appear to be closely linked to temperature and precipitation and vulnerable to climate change. Such atmospheric processes are considerable and more complex than for CO2. As such, the processes and drivers that govern methanogenesis and CH4 reduction and consumption are still the subject of active research. Also hampering ground-based measures is our inability to discern to which extent different physical mechanisms transport CH4 from the soil and the biosphere into the atmosphere (*i.e*., ebullition, diffusion, aerenchyma pumping, or pressure pumping). New aerial measures of CH4 derived from the CARVE project demonstrate emissions are not regionally homogenous, but show higher concentrations along large riverbeds and different geologic substrates, which themselves would require additional research in their own right.

The current terrestrial infrastructure in the Arctic is limited, primarily due to rough logistical and climatic conditions. Constrained to a select number of countries they include the Interact (pan-Arctic field stations), the ITEX (pan-Arctic heating experiment (now retired), the Swedish ICOS tower-based project, the Norwegian ICOS study of fluxes from terrestrial regions, ocean and atmospheric levels, the NSF NEON and US NSF AEON tower-based projects, the US DOE NGEE bio- geochemistry study, the US NASA Carve boundary layer flights research (now retired, the US NASA ABOVE integrated aircraft and towers project (in the US and Canada) and the EMSO European Multidisciplinary Seafloor and water-column Observatory.

In the Arctic oceanic and coastal environments, a relatively new source of CH4 has been reported in methane hydrate production, which is venting through the oceans and could potentially significantly contribute to atmospheric concentrations. There are large amounts of CH4 stored in the world's oceans and seafloor (particularly at higher, colder latitudes) in a solid hydrate form (clathrates). They are thought to be located on ocean floors where sediments can bio-accumulate and as such, are extremely spatially heterogeneous and difficult to detect. It is considered cold water temperatures (slow reaction rates), near coastal areas (bio-accumulation sources) and deep water (pressure) are essential to the formation of these deposits. But as ocean temperature warm, there is real concern regarding additional and possibly rapid release of solid CH4 due to its destabilization into gaseous form. Attempts to estimate methane hydrates fluxes are even more difficult than terrestrial CH4 research, as hydrates require ships, ship time and sea floor observatories (EMSO). Because of such constraints, measures are collected through ad-hoc cruises and even when large deposits are formed, their fluxes into the atmosphere are spatially heterogeneous. However, Methane hydrates being a potential energy source,, energy exploration may serendipitously help scientists access and study these CH4 reserves.

Nevertheless long-term, consistent measurements (ground and air and sea) are lacking, as are consistent CH4 measurement methodologies (*i.e*., CH4 filtering, gap- filling procedures, spatial distribution of tall towers which currently do not exist and flask sampling, etc...). The logistics to conduct science in the Arctic are clearly challenging, with limited access, cold temperatures and 24h of daylight during the summer (and conversely in the winter). These research questions answer strong societal imperatives, and would warrant the release ofnew and immediate resources despite the challenges facing researchers working in the Arctic. CH4 releases into the Arctic way have international implications for our society, as many circumpolar countries have a stake in this issue. Through the Arctic Council and in accordance with the Galway declaration, intergovernmental cooperation tools should be exploited to overcome legal and geopolitical barriers and conduct the appropriate research.

4. Simulating and monitoring O_3 and CO_2 deposition / coupling / interaction

Ozone is a highly reactive, toxic oxidant for plants and is responsible for a decrease in the carbon assimilation of plant ecosystems. This secondary pollutant is photochemically formed, especially in areas in which high UV radiations are associated to high temperatures and the presence of volatile precursors, such as NOx and VOCs.

This molecule is present in the atmosphere in trace concentrations (less than 100 ppbv) and is capable of inhibiting carbon assimilation in agricultural and forest ecosystems. Ozone is a lot more difficult to measure than other non-reactive greenhouse gases. However, UV-based and new chemiluminescence sensors enable precise and fast measurements and their use in experimental infrastructures is highly desired.

Direct flux measurements in the field, using micrometeorological techniques in association with latent heat flux measurements, allow for the partition of ozone fluxes into different sinks on the soil-plant continuum: i) Stomata, ii) adsorption on plant surfaces and iii) gas-phase reactions with reactive VOCs and NOx. Experimental evidence suggests stomata alone are responsible for 40 to 80% of the ozone removed by vegetation. Tropospheric O3 formation generated by photochemical reactions involving BVOC and O3 must be also taken into account in O3 budgets.

So far, ozone risk assessments have been based on manipulative experiments. Present regulations in assessing critical ozone levels are mostly based on estimated accumulated exposure over a threshold concentration. There is however a scientific consensus on flux estimates being more accurate, because they include plant physiology analyses and different environmental parameters that control the uptake – and not just the exposure -- of ozone.

Long-term Eddy Covariance measurements offer a great opportunity to estimate carbon assimilation at high temporal resolutions, so as to study the effect of climate change on photosynthetic mechanisms. Recent studies suggest wavelet and multivariate statistical analyses may support our interpretation of ozone damage to vegetation – provided ozone covariations with environmental factors (such as light and temperature) are properly taken into account.

While the scientific community is involved in establishing long-term research infrastructures to measure carbon assimilation in response to climate changes (e.g. ICOS network), the adoption of low-cost fast ozone sensors for Eddy Covariance measurements would constitute a valuable effort in bettering our understanding of carbon assimilation in response to environmental stresses.

CONCLUSIONS

IMPACT ON PROJECT

The workshop was a key element in finding out some of the most pressing scientific questions which could be answered via interdiciplinary collaboration. The workshop results are particularly useful for the rest of the Theme I work packages in technical developmen priorities and to the cluster strategic prioritization actions in WP18.

IMPACT ON STAKEHOLDERS

The deliverable is also important factor for the RI prioritization, particularly in the context of international and cross-diciplinary collaboration.